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ABSTRACT

Background: Paralympic sports provide opportunities for those who have an impairment that might otherwise be a barrier to participation in regular sporting competition. Rifle shooting represents an ideal sport for persons with vision impairment (VI) because the direction of the rifle can be guided by auditory information when vision is impaired. However, it is unknown whether those with some remaining vision when shooting with auditory guidance would be at an advantage when compared with those with no vision at all. If this were the case then it would be necessary for those with and without remaining vision to compete in separate classes of competition.

Materials and method: The associations between shooting performance and 3 measures of visual function thought important for shooting were assessed for 10 elite VI shooters currently classified as VI. A conventional audiogram was also obtained.

Results: The sample size, though small, included the majority of European VI shooters competing at this level. The relationships between visual functions and performance confirmed that individuals with residual vision had no advantage over those without vision when auditory guidance was available. Auditory function was within normal limits for age, and showed no relationship with performance.

Summary: The findings suggest that rifle-shooting athletes with VI are able to use auditory information to overcome their impairment and optimise performance. Paralympic competition should be structured in a way that ensures that all shooters who qualify to compete in VI shooting participate within the same class irrespective of their level of VI.

Summary of the new findings

- No association found between visual function and shooting performance in athletes with vision impairment (VI).
- Athletes with VI are able to use auditory information to overcome their impairment and optimise performance.
- Paralympic VI athletes should compete within the same class irrespective of their level of VI.

INTRODUCTION

Paralympic sports provide opportunities for people with impairment, and participation has continued to grow with an increasing number of athletes participating at both the grass roots and elite levels of competition. In order to provide structure and ensure a fair and equitable competitive environment, athletes undergo *classification* to group athletes into classes, so that they compete against others with a similar level of impairment.[1 2] The International Classification of Functioning, Disability and Health (ICFDH) is currently the most widely accepted classification of health and ability, and any robust classification structure for sport should make appropriate reference to the ICFDH.[3] Any classification structure should describe appropriately the types and severity of impairments and additionally consider their functional effects.[4] During classification, if an athlete is determined eligible to compete then they will be placed into a class according to the degree of activity limitation caused by the impairment. Different classes ensure that athletes compete against other athletes of equivalent levels of impairment. By minimising the perceived inequities between athletes, accurate classification helps to legitimise competition and promote participation in Paralympic and disabled sport.

The *Classification Code* of the International Paralympic Committee (IPC) explicitly details the need for the development and implementation of robust classification systems that are evidence-based and sport-specific.[4 5] Although this process has for some time been underway for athletes with physical or intellectual impairments, at this stage there has been no change to the classification systems for athletes with vision impairment (VI). The current system for athletes with VI is medically based, grouping athletes on the basis of their performance of clinical tests of vision and therefore does not take into account the effect of the impairment on sport performance.[4 5] Moreover, the system does not delineate impairment from limitation of activity as distinguished in the ICFDH. All visually impaired athletes are classified according to the same criteria, irrespective of the sport, and hence the visual demands that may be required for the particular sport are not considered. This could mean that some visually impaired athletes are competing on an unfair basis, that is, they compete against opponents who may have an impairment that causes less impact on performance than their own impairment does. Furthermore, it could be that rather than promoting inclusivity, some athletes are excluded from competition even though their level of visual function impairs their ability to compete equitably with fully sighted athletes.

The current classification system used by almost all sports that cater for athletes with VI consists of the measurement of two elements of visual function: visual acuity (VA) and visual fields (VFs). Following confirmation that there is an underlying medical condition that can explain the measured level of visual function, all athletes are examined and classified into one of three classes on the basis of their VA or VF (B3, B2 or B1, from the lowest to highest level of impairment). The cut-off criteria that separate these classes were designed arbitrarily on the basis of the definitions of low vision and blindness outlined by the WHO.

This means that there is no evidence to show that the classes reliably represent categories of impairment that have different effects on sport performance, and as a result some sports have abandoned the three classes and have decided to group all athletes together within the same class (eg, judo). This would particularly be the case for sports where those with some remaining vision are presumed to have no advantage over those who are completely blind.

Shooting is a sport of particular interest to athletes with VI because, in the adapted form of the sport, competitors can rely on sound rather than (or in addition to) vision to guide the direction of the gun barrel towards the target. The air rifle is electronic and fitted with an acoustic mechanism that allows the athlete to 'sight' via an audio signal: the closer to the target the athlete aims, the higher in pitch the tone becomes with the pitch being the same in both ears; that is, that there is no auditory cue as to localisation. This aiming mechanism is mounted on the air rifle, with the athlete listening to the signal through headphones directly connected to the device. Bullets are fired and the score is measured optoelectronically. This system facilitates not only an accurate score, but also allows the athlete or their assistant to see, on a nearby monitor, the outcome of each shot. These adaptations to the sport make it highly accessible and attractive to persons with high levels of VI.

Unfortunately, VI shooting is not currently included in the Paralympic games as a stand-alone sport. One of the primary reasons is that the sport must develop, in accordance with the IPC Classification Code, an evidence-based system of classification specific to the sport. This means that the sport must provide evidence to demonstrate (1) the minimum level of impairment necessary for inclusion in competition (the *minimum impairment criteria*), and (2) whether the eligible athletes should compete together in one class or be separated into separate classes.[5] Related to the second point, separate classes would be necessary if vision was related to performance, that is, if those with better visual function performed better than those with poorer vision. In contrast, if the auditory guidance used in the adapted form of the sport would be sufficient to replace (or even improve on) visual information, then residual vision in VI athletes should provide no advantage when shooting. That is to say, the level of VI should not impact performance and therefore all athletes should be able to compete within the same class.

The aim of this study was to determine whether a significant relationship exists between vision and performance in VI shooting. Elite VI shooters took part in a Grand Prix competition, and their performance scores were correlated with three measures of visual function deemed important in shooting. The results were expected to establish whether vision is required for success in VI shooting (when auditory guidance is available). From a practical standpoint, the findings help to determine whether separate classes would be required for VI shooting, thereby removing one of the key barriers to the inclusion of the sport in Paralympic competition.

METHODS

Participants

Ten elite athletes in the sport of VI shooting took part in the study. All were competing in an international Grand Prix meet organised specifically for the project and funded by the German Federal Ministry of the Interior. Participation in the study was voluntary; however, all 10 athletes attending the event agreed to participate in the project without remuneration or any other incentive. All participants were highly ranked competitors from European countries and competed regularly at an international level. This sample, while small, therefore represents a significant proportion of the elite visually impaired shooting community. The Faculty Research Ethics Panel at Anglia Ruskin University, Cambridge, UK, gave ethical approval for the study. All participants provided informed consent and the research was conducted in accordance with the tenets of the Declaration of Helsinki.

Procedure

Visual function

Three tests of visual function were performed under standardised conditions (light level 200 lux) for each athlete:

1. *Visual acuity*: VA represents the ability to recognise high contrast characters that vary in size. Distance VA was determined both binocularly and monocularly following the procedure of Bailey *et al*.[6] Specifically, a handheld ETDRS LogMAR letter chart was held at 4 m (2000 Series Revised, Precision Vision, La Salle, Illinois, USA), with the viewing distance reduced to 2 and 1 m if the participant could not read the largest letters on the chart. Letter by letter scoring was used with the acuity measured in logMAR units. If the VA was too poor to be recorded using the letter chart (VA >1.60 LogMAR), the Berkeley Rudimentary Vision Test (BRVT)[6] (Precision Vision, La Salle, Illinois, USA) was used. If the athlete could not see the maximum letter size (LogMAR 2.60) at the closest test distance then a standard test of light perception was performed. Near VA was measured both binocularly and monocularly using a SLOAN two-sided ETDRS Format Near Point Test LogMAR reading card (Precision Vision, La Salle, Illinois, USA) and recorded in LogMAR units. For all acuities, smaller logMAR scores indicate better VA.
2. *Contrast sensitivity*: Contrast sensitivity (CS) represents the ability to detect differences in brightness between characters (of a constant size) and their background. CS was measured both monocularly and binocularly using a Pelli-Robson chart[7] at 1 m. Higher logCS scores indicate better CS.
3. *Visual fields*: VFs represent the sensitivity of vision in the central/peripheral areas of the VF. VFs were assessed monocularly using a Henson 9000 Field Analyser (Topcon GB Ltd, Newbury, Berkshire, UK; Zata Fast 30/24–2′ strategy). The mean defect in sensitivity was recorded relative to the age-expected sensitivity in decibels (dB). Smaller mean defect scores indicate better peripheral sensitivity.

Hearing

The use of an audio signal in VI shooting highlights the importance of adequate hearing, a factor that is not taken into consideration during the determination of eligibility to compete. To check whether shooting performance was related to hearing, a hearing assessment was conducted using pure tone audiometry over the range 0.25–8 kHz (Siemen's Unity 3 audiometer and DD45 headphones). Testing took place in a quiet room (ambient noise ≤35 dB(A)) with hearing thresholds obtained within 5 dBHL according to the procedure outlined by the British Society of Audiology.[8] Two metrics were chosen to assess hearing acuity: (1) the four-frequency average hearing thresholds (4FA), defined as the average of the hearing thresholds (in dBHL) of the better ear at octave frequencies between 500 Hz and 4 kHz (inclusive; a smaller value represents better hearing); and (2) the largest octave difference (LOD), defined as the largest difference (in dB) between two thresholds an octave apart on the audiogram (between 250 Hz and 8 kHz). The LOD provides an estimate of how rapidly any impairment alters as a function of frequency (or how 'steep' the slope of the hearing loss is on the audiogram). The larger the value, the more rapidly the hearing loss progresses across the test frequencies.

Shooting performance

There are two different 10 m air rifle competition events for VI shooting: *prone* and *standing* events. In the prone competition, the athlete is allowed to sit on a seat without a backrest and rest their arm and rifle on a table (<90 cm diameter). In the standing position, the athlete must support the weight of the rifle while shooting. VI athletes are permitted to ask a sighted assistant to aid them in their set up and general positioning, but not with the actual shot.

According to the rules of the International Blind Sports Federation, competition takes place across two rounds, a *qualifying* and *final* round, with men and women competing against each other. In the qualifying round, athletes shoot 60 times at a target of 10 concentric rings, with the athlete scoring 10 for a hit in the central ring, 9 for the next, and so on. The eight best scoring shooters progress to the *final* round in which the 10 rings are subdivided into 10 score zones, each representing an increment of 0.1 (so the highest score for an individual shot is 10.9). During the final, the lowest scoring athletes are progressively eliminated from the competition and the best scoring athletes remain. The cumulative scores determine the final positions; however, the nature of the elimination process means that athletes take an unequal number of shots during the final.

In our study, performance was assessed during both the prone and standing events, each held on two consecutive days. The score after the qualifying round was used as the primary outcome measure, as it was the score that was available for all participants and for which each participant took an identical number of shots. We also recorded the performance of the eight competitors in the final and used their scores as a secondary outcome measure.

Data analyses

A preliminary check found that the qualifying scores were not normally distributed, and so we proceeded to use non-parametric statistical testing. Kendall τ correlations were used to evaluate the strength of association between measures of visual function and shooting performance. Differences between the means of different groups or conditions were assessed using the Wilcoxon signed-rank test. The α was set at 0.05 for all testing. None of the conclusions made on the

Table 1 Participant details, visual function and shooting scores

Athlete DVA	Age	Sex	Years competing	Vision NVA	CS	VF	4FA	Hearing LOD	Qualifying	Score (standing) Final	Qualifying	Score (prone) Final	
1	50	M	20	0.24	0.26	1.05	33.19	8.7	40	558	DNQ	DNC	DNC
2	65	F	4	0.82	0.92	0.45	19.78	12.5	30	563	198.5	584	143.1
3	31	M	8	1.02	0.72	0.60	16.72	2.5	15	562	70.0	594	165.1
4	63	M	5	1.52	0.68	0.45	8.66	17.5	35	581	158.2	600	210.4
5	45	M	9	1.64	1.22	0.15	19.19	10.0	25	578	115.6	600	209.1
6	42	M	9	1.80	1.18	0.15	32.58	16.2	25	547	DNQ	DNC	DNC
7	51	F	2	2.20	1.10	0.00	27.68	11.2	15	577	198.2	579	83.6
8	29	M	17	PL	PL	NM	NM	3.7	10	586	137.0	DNC	DNC
9	37	F	25	NPL	NPL	NM	NM	8.7	20	582	178.0	599	185.9
10	37	M	13	NPL	NPL	NM	NM	4.0	45	576	95.5	577	123.1

CS, monocular contrast sensitivity in the shooting eye (logCS); DNC, did not compete; DNQ, did not qualify; DVA, monocular distance visual acuity in the shooting eye (logMAR); F, female; 4FA, pure tone audiometry threshold averaged across four octave frequencies 500 Hz–4 kHz (dBHL); LOD, largest difference in hearing thresholds between neighbouring octaves (dB); M, male; NM, not measurable; NPL, no perception of light; NVA, monocular near visual acuity in the shooting eye (logMAR); PL, perception of light; VF, visual field mean defect in the shooting eye.

basis of non-parametric testing would have changed if parametric tests were used.

RESULTS

Shooting performance

Qualifying scores in the prone competition were significantly higher than those for the standing competition (table 1; Wilcoxon signed-rank, Z=−2.37, p=0.02). As the results of one competition did not predict the results of the other (no correlation between qualifying standing and prone scores, Kendall τ=0.29, p=0.36), it was considered important to relate both scores to visual and auditory performance independently.

Vision

Table 1 shows the demographic characteristics of the participants along with the results for the tests of monocular visual function in the eye used during shooting. All athletes reported shooting with the eye measured as having better visual function. As there were no significant differences between binocular function and monocular function in the better eye, table 1 shows only the results for monocular visual function for the better eye (used during shooting).

Qualifying scores for each discipline were compared with visual function (figure 1A–D). The figure shows no apparent relationship between the score achieved in either discipline and any of those for visual function. Correlations between visual function and qualifying score were not significant (Kendall τ, p>0.08; details given in legend to figure 1). The most striking finding is that the competition scores of those with worse vision do not appear to be worse than those of the athletes with better vision. If anything, the best performing athletes were those who had the lowest levels of visual function (highest logMAR and VF scores plus lowest CS scores; see correlation coefficients in figure 1 legend).

To investigate further, shooters were categorised as sighted (ie, having measureable field, VA and CS) or non-sighted (ie, no measurable visual function). There was no difference in the qualifying round standing performance of sighted (n=7, median=572) and unsighted (n=3, median=579) shooters (Mann–Whitney U=3.0, z=−1.71, p=0.09), nor in their final scores in the standing competition (Mann–Whitney U=6.0, z=−0.45, p=0.66; sighted: n=5, median=158.2; unsighted: n=3, median=136.8). During prone competition, there was also no difference in the qualifying round performance of sighted (n=5, median=594) and unsighted (n=2, median=588) shooters (Mann–Whitney U=3.0, z=−0.78, p=0.43), nor in the final scores (Mann–Whitney U=4.0, z=−0.39, p=0.70; sighted: n=5, median=165.1; unsighted: n=2, median=154.5).

Hearing

All participants had sufficiently good hearing to allow the tone signal to be heard across the majority of

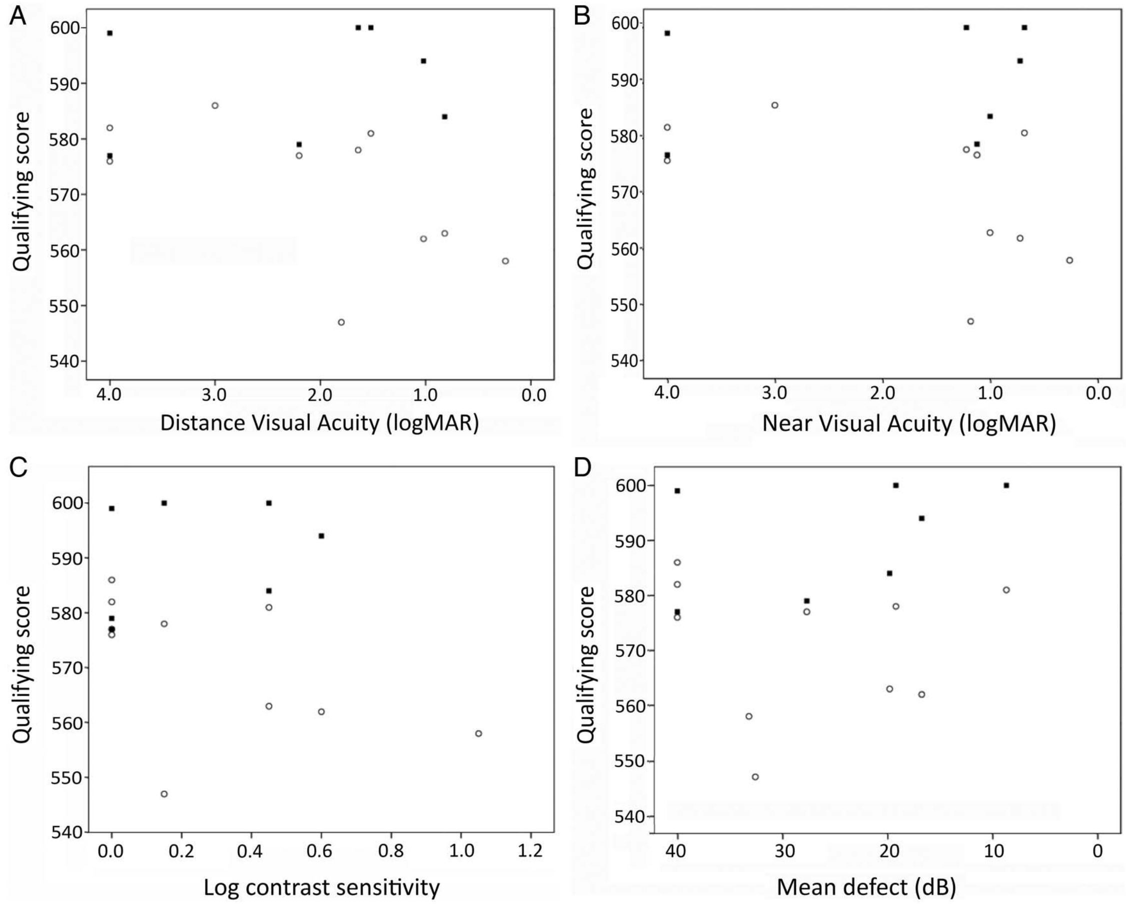

Figure 1 Shooting scores of participants in the qualifying rounds of the standing (open circles) and prone (filled squares) competition as compared with visual function. Note that in all graphs function improves from left to right and from bottom to top. (A) DVA (participants with perception of light given a score of 3 logMAR, and those with no perception of light a score of 4 logMAR: RHS of x-axis; Kendall τ correlations: standing vs DVA: τ+0.36, p=0.15; prone vs DVA: t-0.15, p=0.65); (B) near visual acuity (participants with perception of light given a score of 3 logMAR, and those with no perception of light a score of 4 logMAR: right hand side of axis; Kendall τ correlations: standing vs NVA: t-0.35, p=0.28; prone vs NVA: τ+0.36, p=0.15); (C) contrast sensitivity (participants with no measurable function given a score of 0.00 logCS: left hand side of x-axis; Kendall τ correlations: standing vs CS: τ −0.47, p=0.08; prone vs CS: τ+0.33, p=0.34), and (D) visual field mean defect in the shooting eye (participants with no measurable function given a score of 40 dB: RHS of x-axis; Kendall τ correlations: standing vs MD: τ+0.09, p=0.72; prone vs mean deficit: t-0.55, p=0.09). CS, contrast sensitivity; DVA, distance visual acuity; NVA, monocular near visual acuity in the shooting eye.

audible frequencies in at least one ear. Three individuals had all hearing thresholds classified as 'normal', five had age-consistent mild high-frequency hearing loss (classified as any threshold values between 25 and 40 dBHL inclusive), and had a mild high-frequency sloping hearing loss in one ear, and moderate high-frequency sloping hearing loss in the other (the two oldest individuals). Table 1 shows the results for average thresholds in the better ear (representing overall hearing sensitivity) and the largest difference between neighbouring octaves. Neither the average thresholds (4FA) nor the largest difference between neighbouring octaves (LOD) were related to qualifying scores in either competition (Kendall τ, standing vs 4FA: t-0.14, p=0.59; prone vs 4FA: τ+0.29, p=0.36; standing vs LOD: t-0.25, p=0.32; prone vs LOD: τ+0.05, p=0.88), supporting the conclusion that hearing did not influence performance.

In three individuals, the profile of hearing loss was typical of noise-induced hearing loss. In one individual, a keen musician, this was symmetrical between the ears, and in two individuals was more pronounced on the left. This could be consistent with exposure to firearms for a right-handed shot (ie, rifle resting on the right shoulder), although both reported only shooting with air rifles.

DISCUSSION

The aim of this study was to determine whether a significant relationship exists between vision and performance in VI shooting. The strength of association between three measures of visual function and in-competition shooting performance was evaluated for 10 elite shooters with VI (the majority of European VI shooters competing at international level). Comparison of figure 1A–C shows that, far from there being a positive relationship between visual function and shooting performance, the relationship, though non-significant, is such that better shooting performance was generally achieved by the athletes with poorer vision. When questioned, all of the athletes emphasised their reliance on the auditory information for targeting and not on the ability to see the target or the screen. The modifications made to the sport of VI shooting therefore appear to successfully render the sport equitable for those within the range of visual impairments examined, providing support for the idea that one competition class is sufficient for fair competition in visually impaired shooting.

The finding that performance scores do not depend on visual function raises two important questions. First, it seems fair to ask what might be the factors that do influence performance if vision does not. Clearly the ability to use auditory information is an important factor in VI shooting. But if we consider *sighted* shooting (which does not rely on auditory information), the factors that best predict performance are the aiming accuracy, stability of hold, cleanness of triggering (the final movement of the aim in the final 0.2 s) and timing of triggering.[9] Performance in these aspects may rely on an athlete's ability to maintain concentration and control anxiety,[10 11] factors that are unlikely to be dependent on vision. However, performance in these aspects may also be dependent on the ability to maintain balance,[12 13] and there is strong evidence that postural stability is reduced in people with visual impairment.[14–16] Physical exercise has been shown to improve balance in those with visual impairments.[17 18] The elite athletes assessed here may therefore be less susceptible to the effects of their visual impairment on postural control, and/or the standing and prone protocols used in visually impaired shooting may also reduce the dependence of results on postural control to some extent.

The second question raised by the results related to the level of visual function that should be necessary for an athlete to be eligible to compete in VI shooting (ie, the minimum impairment criteria). In this study, we have shown that vision does not impact the performance of those presently included in competition, and so only one class is necessary for fair competition in VI shooting. However, this does not tell us what the minimum level of impairment should be to be included in competition. The minimum impairment criterion is currently defined as the level of impairment that should limit the ability of the athlete to compete equitably against athletes without impairment.[1] This means that it should be the least impairment that impacts performance *without* the auditory guidance of targeting as that is the situation in the non-adapted format of the sport (ie, when vision is required for targeting). As a result, it will be necessary to determine the level of visual function at which sighted shooting performance is adversely affected (eg, through the simulation of VI[19 20]) to determine the minimum impairment criteria.

Given the strong reliance on auditory information in VI shooting, it should not be surprising that all participants had levels of hearing sufficient to detect changes in the acoustic signal in at least one ear. Some participants did have mild hearing loss, though we did not find a relationship between hearing ability and performance. In part, this is due to the relatively mild nature of the hearing loss; if more severe hearing losses were present, then we expect that an athlete in this discipline would be significantly disadvantaged. The presence of a mild high-frequency hearing loss in a VI shooter, as we saw for several individuals in this test population, provokes an interesting consideration: in such cases, the individual may notice that the tone becomes quieter, as well as higher pitched, when they direct the rifle closer towards the target. Potentially this additional loudness cue might *help* an individual to use the acoustic signal for targeting. If this were the case then the effect would be strongest when the sensitivity in hearing moves from normal to impaired across a narrow frequency range; a so-called steeply sloping hearing loss. We did not observe this in our participants; however, further research is required to determine if there is a level or profile of mild hearing loss that provides competitors an advantage, and at what severity of hearing loss participants experience a significant disadvantage.

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Patient consent Obtained.

Ethics approval The Faculty Research Ethics Panel at Anglia Ruskin University, Cambridge, UK.

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